Microstructure Turbulence Characteristics Of A Shallow Water Column During A Storm Front: Direct Measurement Of Heat Flux And Rate Of Production And Dissipation Of Turbulent Kinetic Energy

Manhar R Dhanak (PI) and Ken Holappa (Co-PI)
Department of Ocean Engineering
Florida Atlantic University
777 Glades Road
Boca Raton, Fl 33431.
phone: 561-367-2827 fax: 561-367-3885 email: dhanak@oe.fau.edu
Award #: N000149615023
http://www.oe.fau.edu/~manhar/awe

LONG-TERM GOALS

The principal long-term goal of this work is to contribute to the development of physics-based numerical models for accurate assessment and prediction of the ocean environment. Such models are required, for example, for rapid environmental assessments preceding MCM operations. Our contribution is based on developing accurate parameterization of the active small-scale processes in the water column through observations from fixed and mobile AUV platforms. The parameterizations are needed to correctly model subgrid scale processes in predictive numerical models. The aim is to develop the necessary data bank to help parameterize the sub-grid processes under various, measured background conditions.

OBJECTIVES

The specific objectives of the present project are (a) To develop a data bank of four dimensional measurement of turbulence in the shallow water column during adverse atmospheric conditions, including distribution of the Reynolds stress, the heat flux, and the rates of production and dissipation of kinetic energy in the upper mixed layer and the bottom boundary layer for validating and formulating sub-grid scale closure models, pertinent to numerical *LES* models for bottom boundary layer and surface mixed layer under adverse atmospheric conditions. (b) To examine the interrelationship between *in-situ* turbulence levels associated with breaking waves in the upper mixed layer and acoustic noise, sonar reverberations and acoustic propagation in the water column.

APPROACH

The following tasks were identified, involving participating in coordinated scientific missions in collaboration with other national and international efforts.

Task 1 The coordinated Adverse Weather (storm - front) Experiment. The experiment was conducted on the SFTF range, in the vicinity of the location 26^0 03.7'N and 80^0 05.56'W, about 2 miles offshore of Ft. Lauderdale, south of Port Everglades. An Ocean EXplorer-series AUV and a smaller AUV, the MADDOG were used to make in-situ turbulence measurement surveys in the upper mixed layer and the boundary layer during a cold front. The AUVs carried the turbulence package, consisting of two shear probes, a microstructure thermistor and a 3-axis accelerometer, developed at FAU, and a self-motion package; the MADDOG also carried a dynamic Pitot tube. The OEX tail section carried a

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Microstructure Turbulence Characteristics Of A Shallow Water Column During A Storm Front: Direct Measurement Of Heat Flux And Rate Of Production And Dissipation Of Turbulent Kinetic Energy**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Atlantic University,Department of Ocean Engineering,777 Glades Road,Boca Raton,FL,33431**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

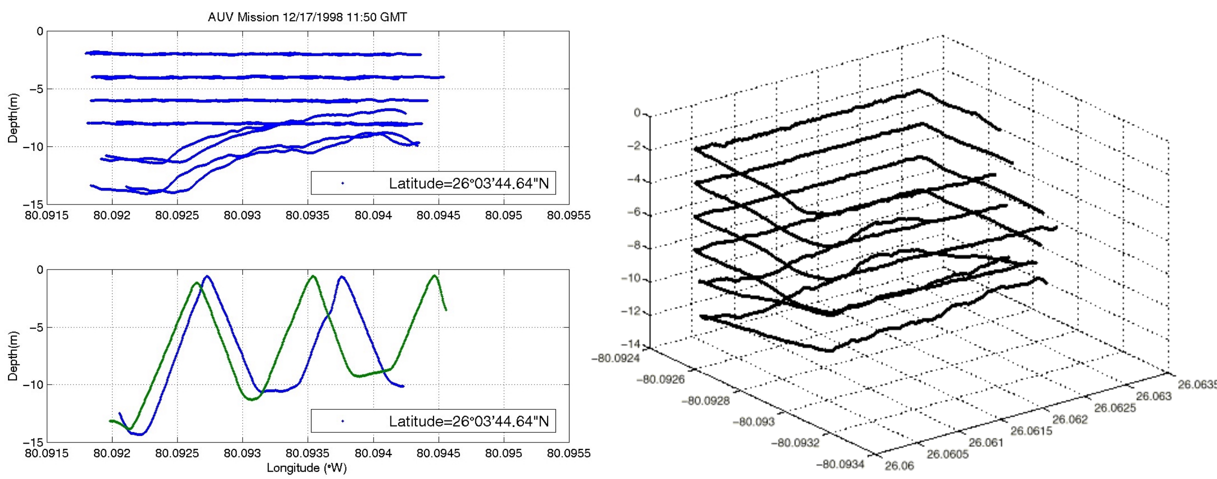
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Falmouth CTD package, a 1200kHz ADCP and a GPS navigation system. The Bottom-mounted instruments consisted of (i) PEACOCK, passive sonar developed at FAU, for measurement of ambient noise from breaking waves. The ambient noise is associated with bubble plumes generated from the air entrapped by the spilling breaker. (ii) A 5-head ADCP, which measured currents and the TKE in the water column during the passage of the cold front. Local wind velocity, air temperature, humidity, and solar irradiance were recorded using a MET station mounted on the surface ship.

Meteorological forcing. Weather data were obtained from NOAA buoys at Fowey Rocks and Lake Worth. Local measurements of atmospheric conditions were made using a Met Station.

Ship-based CTD casts. Half-hourly CTD casts were conducted from the surface mother ship close to the box of AUV operations at 26^0 3.83'N, 80^0 5.68'W using a Seabird CTD during Dec. 14 - 18 and on Dec. 21. At the end of each day, CTD measurements along east west transect were made in the vicinity of the box of AUV operations, approximately along the latitude 26^0 3.8'N. From these measurements, composite maps of the water column have been developed, showing the variation of temperature, salinity and water density during each day and with respect to the offshore distance.

AUV operations: Our measurement missions started at dawn. Clear skies during the night enhanced the cooling, through



1a. Path of the OEX on 12/17/98 and 12/21/99 respectively. Three different sampling strategies are depicted. The latitudes and longitudes are in degrees and the depth is in meters.

heat loss by radiation. Typical paths of the OEX AUV during the fall operations is shown in Figure 1a.

Measurement of Heat Flux. Simultaneous measurement of temperature fluctuations *T'* and velocity fluctuations u_i' at points separated by distances much smaller than the correlation radius of the fluctuating signals makes it possible to calculate the turbulent heat flux directly as $Q_i = c_p \rho \overline{T' u_i'}$, where c_p is the specific heat and r the density of water and the index i = 1,2,3. In practice, this is a very difficult measurement to make using a mobile platform. However, Fleury and Lueck [1] have shown that this is possible with a towed vehicle. Precise motion of the AUV is required and involves determination of the Euler angles as well as the influence of wave induced irrotational motion in order to discern temperature measurement from body motion of the vehicle in a manner described by

Wolk[2]. As a result of the measurement, the distribution of $\chi = \frac{1}{2}\overline{T'w'}\frac{\partial T}{\partial z}$, the rate of dissipation of temperature variance, will be determined.

<u>Task2. Turbulence measurement mission in Scottish Waters near Oban (May 1999).</u> This was part of a NICOP project, aimed at examining the interrelationship between breaking waves, Langmuir cells and small-scale turbulence. During two days of operation, high quality turbulence measurements were made with the FAU turbulence package mounted on the Autosub. The Autosub also carried 250Hz side-scan sonar (Steve Thorpe) that was aimed at detecting bubble clouds ahead of the vehicle. Winds reached up to 8m/s and Langmuir cells were visible. We hope to correlate the sonar observations with our turbulence, CTD, ADCP and atmospheric measurements in an effort to examine the distribution of dissipation rates in Langmuir cells.

<u>Task 3</u>. <u>Participation in the Shoaling Wave Experiment - Duck 99</u>. An AUV will be used to profile the bottom boundary layer with CTD and turbulence sensors to within 0.2 meters of the bottom. The surface support vessel for the AUV will conduct CTD and BBADCP measurements of the water column. The mission will be repeated several times during the experiment. Synoptic measurements by the other research groups can later be correlated with the AUV measurements.

<u>Task 4</u>. <u>Test missions</u>
Test missions, leading up to the coordinated missions described in tasks 1 -3 were carried out throughout the year off the coast of Florida. These were in the form of short missions primarily aimed at ensuring that the developed turbulence packages are operational and identifying the relevant parameters necessary in planning the storm-front experiment.

WORK COMPLETED

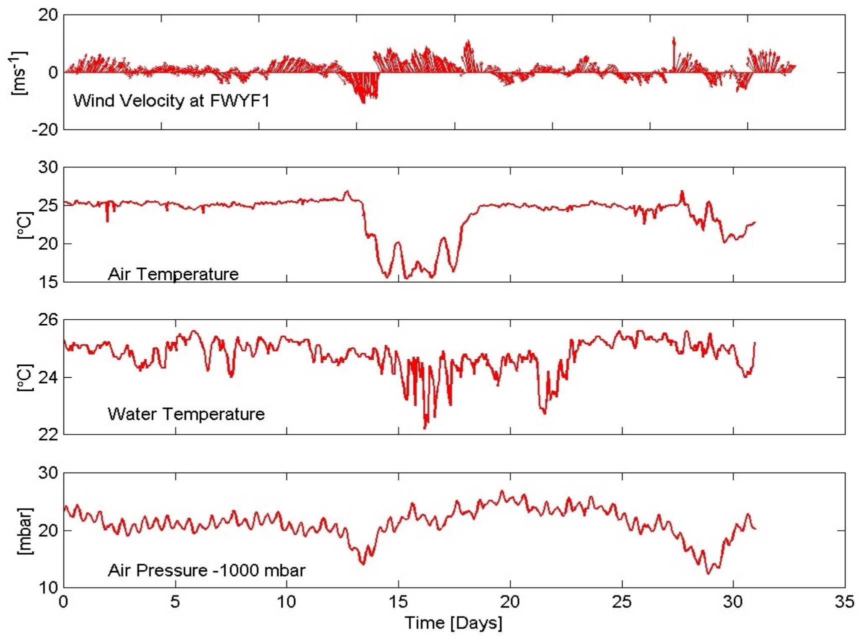
Tasks 1 and 2 were completed in fall 1998 and summer 1999 respectively. Breaking waves were absent during the adverse weather experiment in fall, 1998 so that the PEACOCK did not measure ambient bubble-induced noise. Analysis of the measured data is in progress. Data analysis of the Bermuda mission of August 1998 is also in progress. Additional turbulence measurement missions were carried out during summer 1999 on the SFTF range at the edge of the meandering Gulf Stream in the upper mixed layer. These missions were supported by OSCR HF surface current measurements. Task 3 was attempted in October 1999. MADDOG performed a straight-line test mission at a constant depth of 3 meters. However, the actual mission was called off because of bad weather conditions. Next attempt is being planned for November 1999.

Pressure Probe. In the experiment described in Task 1, three components of microstructure velocity shear were obtained using both a shear probe and the pressure probe. Measurements using the pressure probe have previously been hampered by the short life of transducers in the ocean environment but the most recent design has alleviated this problem. The new design uses two probes to cancel the mean static and mean dynamic pressure from the measured signal, allowing for much greater sensitivity.

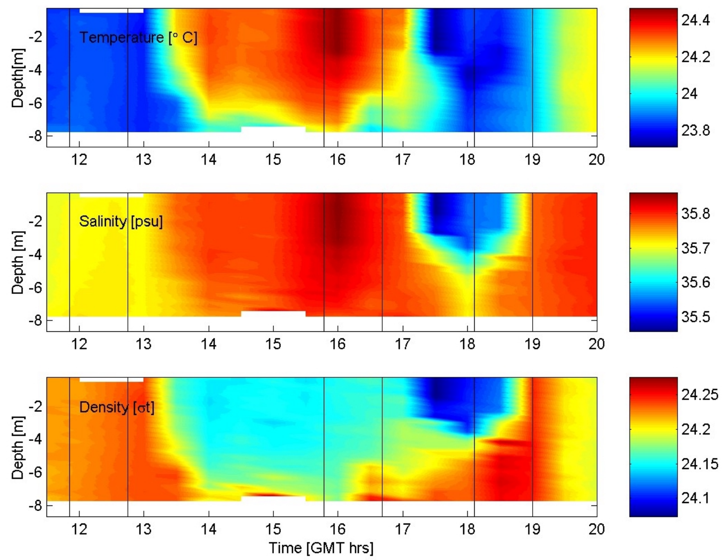
RESULTS

<u>Task 1. Adverse Weather (storm front) Experiment, fall 1998</u>. During the cold front over South Florida, in December 1998, the air temperature dropped by 10^{0}C (Figure 1b). Cold winds blowing offshore, helped by radiative cooling due to clear skies, led to significant convectively driven motion

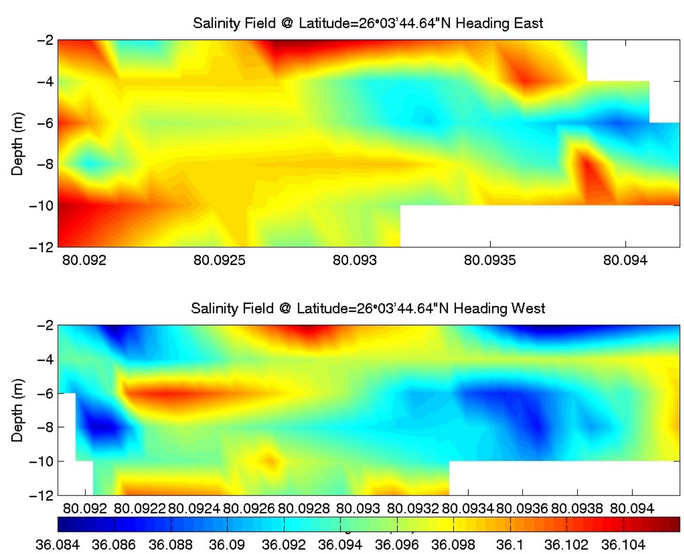
in the shallow water column (depth 50ft), giving rise to relatively high TKE in the water column and associated high rates of dissipation. On Dec. 17 the skies overnight were clear, the weather reports indicating clear skies for 12 hours preceding the measurements. Sample results of the CTD casts from the surface ship for Dec. 17 and Dec. 21 are shown in Figures 1c. Vertical bars on Figures 1c mark the periods of AUV operations. Temperatures in the water column vary by 0.5 ^{0}C, salinity by around 0.3 psu and density by 0.25 kg / m^3 at the location on both the days, indicating well-mixed regions. However, the nature of the variations suggests somewhat more dynamic environment on Dec. 17. The measured TKE during a period of seven days is shown in Figure 1d. Sample turbulent shear and temperature spectra from a 2-minute time series on Dec 21 are shown in Figure 1e and the cross-shelf variation of rate of dissipation in the water column is shown in Figure 1f. Further results are posted at http://www.oe.fau.edu/~manhar/awe. An analysis of the data will be used to parameterize the energy budget in the water column. Typically, as the front moves southeast, the wind direction changes, producing whitecaps. However, during this front, the winds died away soon after the front was past the site and breaking waves did not occur. An in-depth analysis of the significant data will be completed by the end of this year.



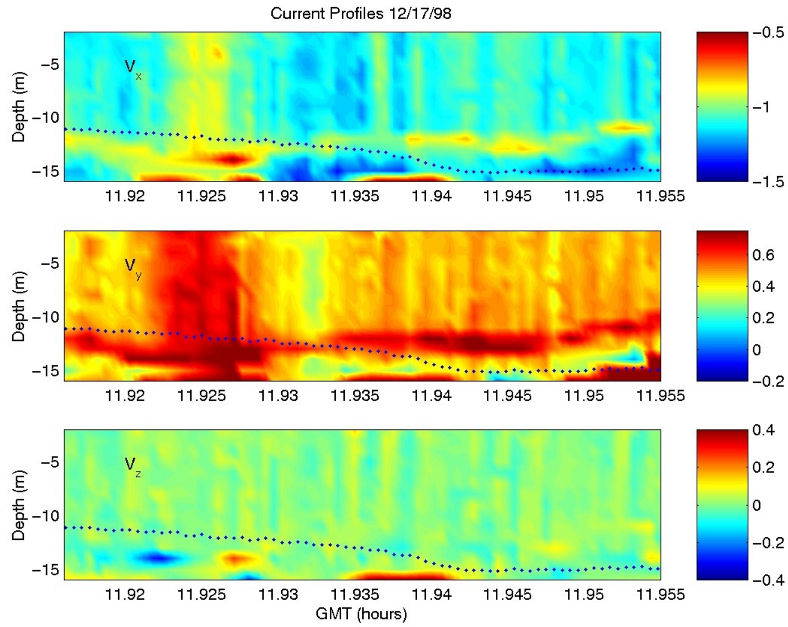
1b. Atmospheric conditions during December 1998, showing the cold spell in the middle of the month. Source: NOAA, C-MAN buoy at Fowey Rocks. S. Florida



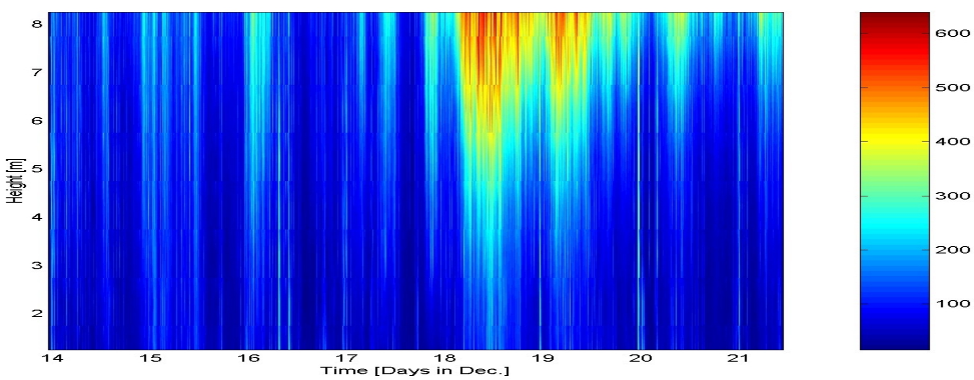
1c. Composite views of temperature, salinity and density during Dec. 17 at 26⁰ 3.83'N 80⁰ 5.68'W, based on periodic CTD casts from the surface ship during the day.



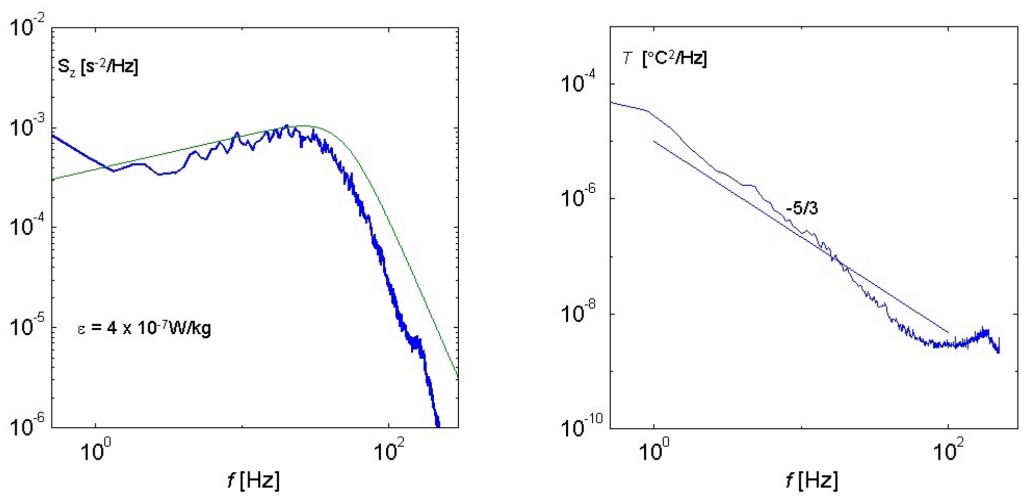
1d. Cross-shelf salinity distribution determined from CTD measurements using an AUV.



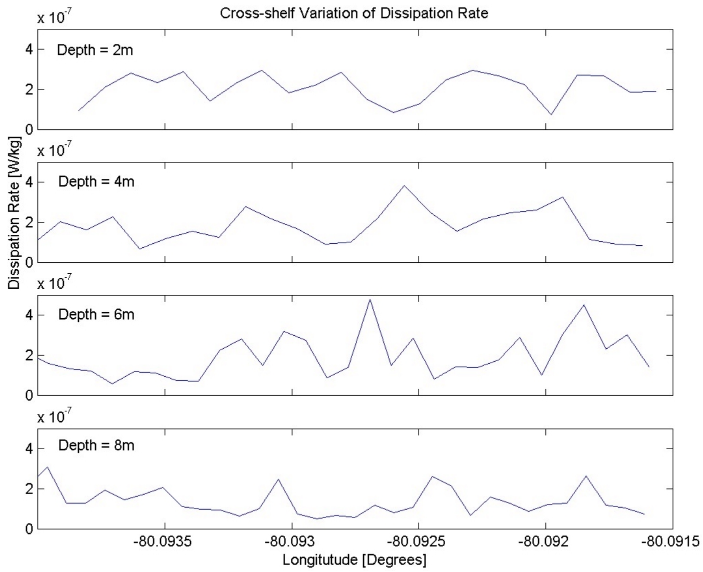
1d. Cross-self, along shore and vertical components of currents in the water column on 12/17/98 as determined by the ADCP on board.



1e: TKE ((cm/s)^2) distribution in the water column over the 5-head ADCP during Dec 14 – 22, 1998 (Analysis by Matt Brennan).

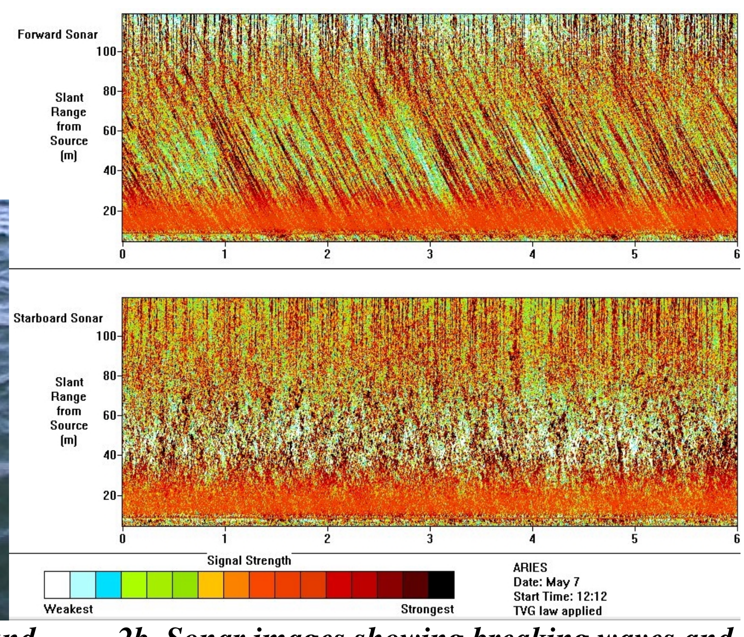


1f: Sample shear and temperature spectra from 2-minute time segment on Dec 21.

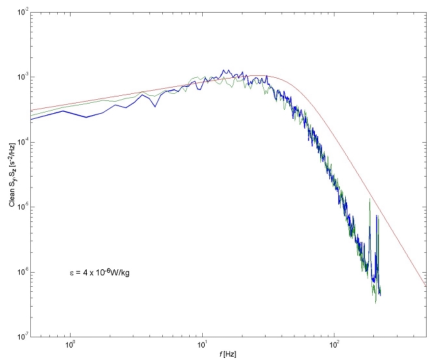


1g. Cross-self distribution of the rate of energy dissipation at various depths on 12/17/98.

<u>Task2. Turbulence measurement mission in Scottish Waters near Oban</u> Figure 2a shows an image of an observed windrow. Sample sonar images are shown in Figure 2b and sample velocity spectra are shown in Figure 2c. The Langmuir cells were fairly weak, however, their presence is clearly evident in Figures 2a and 2b. Good quality microstructure temperature and velocity shear data were obtained as seen in Figure 2c. Analyses of the data in collaboration with SOC scientists are currently in progress.

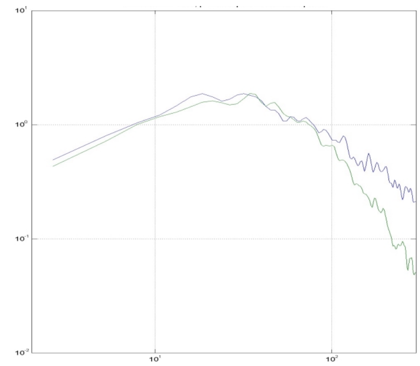


2a. Bubble windrow in Loch Etive, Scotland. ***2b. Sonar images showing breaking waves and weak Langmuir cells.***



2c. Sample shear spectra averaged over a 2 min. time interval.

Dissipation spectra



3. Dissipation Spectra. The green and blue curve respectively represent shear probe and pressure probe measurements.

Pressure Probe Measurements in a Jet. When compared to the pressure probe, the limitations of the spatial resolution of the shear probe above k = 80 cpm, corresponding to a wavelength of 0.0125m, are apparent in Figure 3, in close agreement with the documented limits of the shear probe. In contrast, the spatial resolution of the pressure probe is seen to be good to k = 250 cpm or a wavelength of 4mm which will accommodate high resolution turbulence measurements in the dissipation range in regions of high turbulence levels. It is planned to use the pressure probe measurements together with the shear probe measurements to allow the calculation of the Reynolds stress and energy budget.

IMPACT / APPLICATIONS

Through the fall 1998 Adverse Weather Experiment and further measurement missions in summer 1999, the value of conducting AUV based measurements in conjunction with fixed systems has been demonstrated. Analyses, when completed, will reveal the full extent of this value. The collaborative missions with SOC have proved immensely valuable. As a result participation in major International ocean experiments in the Mediterranean and in the Pacific to water depths of up to 1600m are planned for year 2000 and 2001.

TRANSITIONS

Collaboration with University of Miami, University of Victoria, Canada, Institute of Ocean Sciences, Canada and Southampton Oceanographic Center are underway. The turbulence measurement package is being extended to include sensors for measurement of bubble distribution, microstructure conductivity and dissolved oxygen in the water column.

RELATED PROJECTS

The work is carried out in conjunction with other ONR-322OM/AOSN projects funded at Florida Atlantic University and with NICOP.

BIBLIOGRAPHY

1. Gregg, M. C. 1987. Structures and fluxes in deep mixed layer. In Dynamics of the Oceanic Surface Mixed Layer, ed P. Muller, D. Henderson.

2. Mellor, G.L. and T. Yamada. 1982. Development of a turbulence closure model for geophysical fluid problems. Reviews of Geophysics and Space Physics, 20, 851-875.

3. Yu, Y. 1997: Flow and turbulence in a tidal channel, Ph.D. Thesis, University of Victoria, Canada.

4. Gross, T.F. and R.M. Nowell. 1985. Spectral scaling in a tidal layer. J. Physical Oceanography, 15, 496-508.

5. Gross, T.F. and R.M. Nowell. 1983: Mean flow and turbulence scaling in a tidal boundary layer. Continental Shelf Research, 2, 109-126.

6. Jimenez, J. and A. Pinelli. 1998. Turbulence near walls. 13th US National Congress of Applied Mechanics. Gainesville, Florida. June, 1998.

7. Osborn, T., D. M. Farmer, S. Vagle, S. A. Thorpe and M. Cure. 1992. Measurement of bubble plumes and turbulence from a submarine. Atmos-Ocean 30, 419-440.

8. Grant W. D. and Madsen, O S. 1986. In Annual Review of Fluid Mechanics. 18. pp265-305. 9. Gargett, A. E., 1989. Ocean Turbulence. Ann. Rev. Fluid Mech. 21. 419-51.

10. Maxworthy, T. 1997. Convection into domains with open boundaries. Ann. Rev. Fluid Mech. 29, 327-71.

11. M. R. Dhanak and K. Holappa. An Autonomous Ocean Turbulence Measurement Platform. To appear in the special Microstructure Sensors Microstructure Sensors in JOAT (presented at the ONR Workshop at Mt. Hood, Oregon. October, 1996).

12. Dhanak, M. R. and K Holappa., 1998. Turbulence Measurements off the Florida Coast using an AUV. Oceanology '98. Brighton.

13 Fluery, M. and R. G. Lueck. 1994. Direct heat flux estimates using a towed vehicle. J. Physical Oceanography, 24,801-819.

14 Wolk, F., 1997. Near Surface heat flux measurement with a towed vehicle. MS Thesis, University of Victoria, Canada.

15. Donelan M., Shoaling wave experiment - Duck 99, http://kiowa.rsmas.miami.edu/duck99/, 1998.

16. Osborn T. R. and Crawford W. R. 1980. In Instruments and methods of air-sea interaction. Ed. L. Hasse, F. Dobson and R. Davis. Plenum Press, NY, pp 369-386.

PUBLICATIONS (1998 - 99)

(1) *An Autonomous Ocean Turbulence Measurement Platform.* 1999. M R Dhanak and K Holappa. Journal of Atmospheric and Ocean Technology. Vol. 16, 1506-1518.

(2) Coastal oceanography using a small AUV E. An, M R Dhanak, L K Shay, S Smith and J Van Leer. Under Review.

(3) *MADDOG: An AUV for benthic boundary layer turbulence measurements.* K Holappa and M R Dhanak. Under Review.

(4) Small scale turbulence measurements in the Gulf Stream using an AUV. M R Dhanak, K Holappa and R G Lueck. Poster. AGU Annual Meeting, San Francisco. December 1998. Poster.

(5) SFOMC Facility as a Center for Coastal Ocean Observation. M R Dhanak and M Luther. SeaTech, Dania, Florida. February 1999. Presentation.

(6) Adverse Weather Experiment. at SFOMC: Small AUVs as Measurement Platforms. M R Dhanak SeaTech, Dania, Florida. February 1999. Presentation.

(7) In-situ oceanic turbulence measurements using a mobile AUV platform. M R Dhanak and K. Holappa. 1999. ISOPE, Brest, France. May 1999. Full Paper.

(8) Measurement of small-scale oceanic turbulence using an AUV. M. R. Dhanak and K. Holappa. International Symposium on Turbulence and Shear Flow Phenomena. Santa Barbara, Ca. September 1999. Full Paper.

(9) Using Small AUVs for Oceanographic Measurements. M R Dhanak, E. An, K. Holappa and S. Smith. Oceans '99. Seattle, Washington. September 1999. Full Paper.